4 SCREENING OF CLEANUP TECHNOLOGIES

In this section, cleanup technologies are evaluated following MTCA guidance for possible application to the Upriver Dam Site. Potentially applicable technologies are identified and retained for assembly of site-specific alternatives in Section 5.

This Focused FS builds upon the results of the Draft Final RI Report (Anchor 2004), and is intended to provide sufficient data, analysis, and engineering evaluations to enable Ecology to select a cleanup action alternative that is protective of human health and the environment. Alternatives for sediment cleanup generally have three components:

1. General response actions – major categories of cleanup activities such as natural recovery, containment, or treatment.
2. Cleanup technologies – general categories of technologies such as capping.
3. Process options – specific technologies within each technology type such as alternative cap designs (e.g., sand versus other confining and sequestering media).

In this section, general response actions and cleanup technologies are screened in accordance with the MTCA regulations and associated guidance (e.g., SMS User Manual). Based on the results of the screening, a range of proposed alternatives are identified that use different remedial technologies and strategies to accomplish the overall Site cleanup objective.

Natural recovery of PCBs in sediment may occur over time through a combination of physical, chemical, and biological processes that lower the concentrations at the point of exposure/compliance over time. As discussed above and depicted in Figure 2, site characterization data have documented natural sediment recovery processes, following previous source controls implemented in the basin. Thus, monitored natural recovery is a proven technology and was retained for further consideration in this Focused FS.

Containment involves either confining hazardous substances in situ through placement of cap materials, or confining excavated and/or dredged materials within an on- or off-site engineered disposal facility after removal. Containment technologies have been used extensively in remediation of contaminated sediments. Thus, containment is a proven technology and was retained for further consideration in this Focused FS.

Treatment technologies can potentially reduce the concentration, mobility, and/or toxicity of PCBs. Most prospective treatment technologies rely on ex situ methods that first require removal, followed by chemical destruction, conversion, separation, extraction, or stabilization. Recently, various in situ treatment technologies have also been developed and applied successfully at the field scale, including potentially promising reactive cap/treatment technologies that are currently undergoing pilot-scale testing in the Anacostia River (Washington D.C; http://www.hsrc-ssw.org/anacostia/). To the extent that treatment technologies for sediment PCBs have been successfully demonstrated at the field scale, they were considered in this Focused FS.

As described in various MTCA guidance, the identification of applicable remedial technologies and process options for each general response action should initially consist of a broad evaluation of the applicable remedial technologies that are available and effective in remediating threats identified at the Site. Process options and cleanup technologies may be eliminated from further evaluation on the basis of technical implementability, and may also be screened on the basis of the following three criteria:

1. Effectiveness – Ability to handle estimated volumes and meet cleanup levels, ability to reduce potential human health and environmental risks, and reliability.
2. Implementability – Technical and administrative feasibility, such as the ability to obtain permits for offsite actions and availability of treatment, storage, and disposal facilities.
3. Cost – Differences among process options within particular technology types.

The remainder of this section presents the evaluation and screening of natural recovery, in situ and ex situ containment, removal, and treatment technologies.

4.1 Monitored Natural Recovery

Natural recovery of PCBs in sediment may occur over time through a combination of physical, chemical, and biological processes that lower the concentrations at the point of exposure/compliance over time. Biodegradation of PCBs is a complex process that involves different mechanisms under aerobic and anaerobic conditions. Based on studies of PCB biodegradation in other similar freshwater systems, PCB degradation processes and half-lives on the order of years to multiple decades may be expected.

The site characterization data indicate that sediment PCB levels, particularly in Deposit 1, peak at depths below the sediment surface, and PCB concentrations decrease steadily in shallower intervals. This vertical profile of PCB concentrations, depicted in Figure 2, is typical of natural sediment recovery processes, following previous source controls implemented in the basin. Net sedimentation rates ranging from 0.4 to 1.0 cm/year have been measured in Deposit 1. Along with prior implementation of PCB source controls in the basin, sedimentation and burial below clean surface sediments helps to drive the natural recovery process.

If natural recovery were to be implemented as a response action at the Upriver Dam PCB Site, periodic long-term monitoring would need to be performed to confirm recovery predictions and verify that recovery achieves the cleanup standard(s). Compliance with the cleanup level may be performed using chemical and/or confirmatory biological testing, as appropriate under existing MTCA/SMS regulations. MTCA also requires that Ecology review cleanups no less than every 5 years in those cases where contamination has been left in place, to ensure the remedy remains protective.

Subject to a balancing of environmental benefits and cost compared to other practicable alternatives, as defined by the MTCA regulation, natural recovery is considered implementable and cost effective at the Site. Therefore, monitored sediment natural recovery was carried forward for more detailed analysis in this Focused FS.

4.2 In Situ Containment

Containment can involve both in situ actions, such as in situ caps, and ex situ actions, such as removal and disposal in an upland landfill facility. Each of these technologies is addressed separately in the sections below.

A common response action to control exposure of sediments containing elevated concentrations of chemicals of potential concern, including PCBs, is to place an engineered cap over the materials, and ensure its long-term integrity through implementation of appropriate institutional controls. Since the deposition of overlying clean sediment plays a role in the process of natural recovery, as discussed above, the natural recovery process can be enhanced by actively providing a layer of clean sediment to the target area. This is often referred to as “enhanced” natural recovery or thin sand cap, and generally consists of placing a nominal 6-inch-thick layer of clean sediment over existing contaminated sediments. Alternatively, a thicker cap (typically 1 foot thick with an overlying armor layer) could be constructed over the contaminated sediments to provide more immediate isolation of underlying contaminated sediments.

Surface layers of the cap system would likely be constructed of clean sand, and could be placed by a number of mechanical and hydraulic methods. Capping has been utilized relatively frequently in sediment cleanup projects conducted in Washington State. Monitoring results to date in the region have shown that capping can provide an opportunity for effective and economical sediment remediation, without the risks that can be involved in removing and mobilizing contaminants by dredging.

If selected as part of the overall cleanup remedy at the Site, the final cap thicknesses would be determined as part of remedial design. The cap would be designed to effectively contain and isolate contaminated sediments from the overlying point of exposure/compliance. The cap would be designed to be thick enough and of sufficient grain size to maintain its integrity under reasonable worst-case environmental and human use conditions (e.g., to resist shear stresses under a 100-year flood or log deposition condition; see Section 5.3).

Subject to a balancing of environmental benefits and cost, capping is considered implementable and cost effective. Therefore, in situ capping was carried forward for more detailed evaluation in this Focused FS.

4.3 Removal and Disposal

Removal and disposal of contaminated sediments has been performed within the Pacific Northwest and elsewhere using a range of different process options appropriate for site-specific conditions. Contaminated sediments can be removed by dredging using one or more of the following representative process options:

1. Mechanical Dredging and Transport – Typical mechanical dredging involves the use of a clamshell bucket on a derrick barge, with delivery to a nearshore sediment processing and/or disposal facility. Because this Site is isolated and equipment will

need to be brought to the Site by truck, a contractor would likely use a crane on a small barge to complete the dredging.

2. Trackhoe – Application is limited to nearshore sites in shallow water.
3. Hydraulic Dredging and Transport – Typically utilizing a hydraulic cutterhead dredge to accomplish dredging and delivery of contaminated sediments to a nearshore dewatering and/or disposal site. Because of water quality control requirements, hydraulic dredging would likely require a relatively large temporary (for dewatering) or permanent (for disposal) nearshore confined disposal facility (CDF) or similar process option for this purpose.

There are generally three types of CDFs available for the disposal of contaminated sediments:

1. Upland – With this option, contaminated sediments are dredged and placed in a specially designed landfill that is on dry land, away from the aquatic environment. The landfill would include liners and a special water collection system so that leachate draining through the landfill does not escape and contaminate groundwater. Dredged sediment from the Upriver Dam Site could be disposed at regional landfills such as the Roosevelt facility.
2. Nearshore – A nearshore CDF could potentially be constructed along the shoreline area, either on uplands or within the aquatic environment. In this situation, a berm would be constructed of clean material near the shoreline, but typically there would not be a liner required, particularly for PCBs (because of limited mobility). The lower layer of the area between the berm and the shoreline would then be filled with contaminated sediment, and the surface of the CDF covered with clean sediment or fill material. Nearshore fills create new land that can potentially be used for public shoreline access or other purposes. Nearshore CDFs have often been integrated with upland redevelopment, and can also be sited on existing contaminated sediment areas to provide further efficiencies.
3. Contained aquatic disposal (CAD) – This type of CDF entails building a submerged berm or depression, filling the constructed basin with contaminated sediments delivered by barge, and then capping the facility with clean sediment. Although CAD facilities can also be sited on existing contaminated sediment areas to provide

further efficiencies, potential application within the Upriver Dam area is likely relatively limited.

Subject to a balancing of environmental benefits and cost, dredging (likely using mechanical methods) and upland or nearshore dewatering/disposal is potentially implementable at the Upriver Dam Site. Therefore, such removal and disposal technologies were carried forward for more detailed evaluation in this Focused FS.

4.4 Treatment

In addition to natural recovery and containment technologies, sediment or contaminant treatment technologies were also evaluated in this Focused FS. However, with the exception of certain technologies such as in situ reactive caps (see below), the feasibility of most treatment technologies has not yet been demonstrated for application to contaminated sediments. Moreover, the combined PCB and wider spread metal contamination present within the Site area present a higher level of difficulty for addressing the potential use of available treatment technologies. Sediment treatment was also not carried forward in the Coeur d'Alene Basin FS prepared by EPA (2001) to address metal contaminants present in Upriver Dam and upstream areas. Thus, with the exception of possible in situ reactive cap amendments (see Section 5), treatment of sediments was not carried forward for more detailed analysis in this Focused FS.

5 DESCRIPTION OF CLEANUP ALTERNATIVES

Section 4 describes potentially applicable remedial technologies and process options for the Upriver Dam Site, and evaluates those technologies based on initial MTCA screening criteria including effectiveness, implementability, and cost of application to the Site. In this section, these retained technologies are combined to formulate a range of remedial action alternatives.

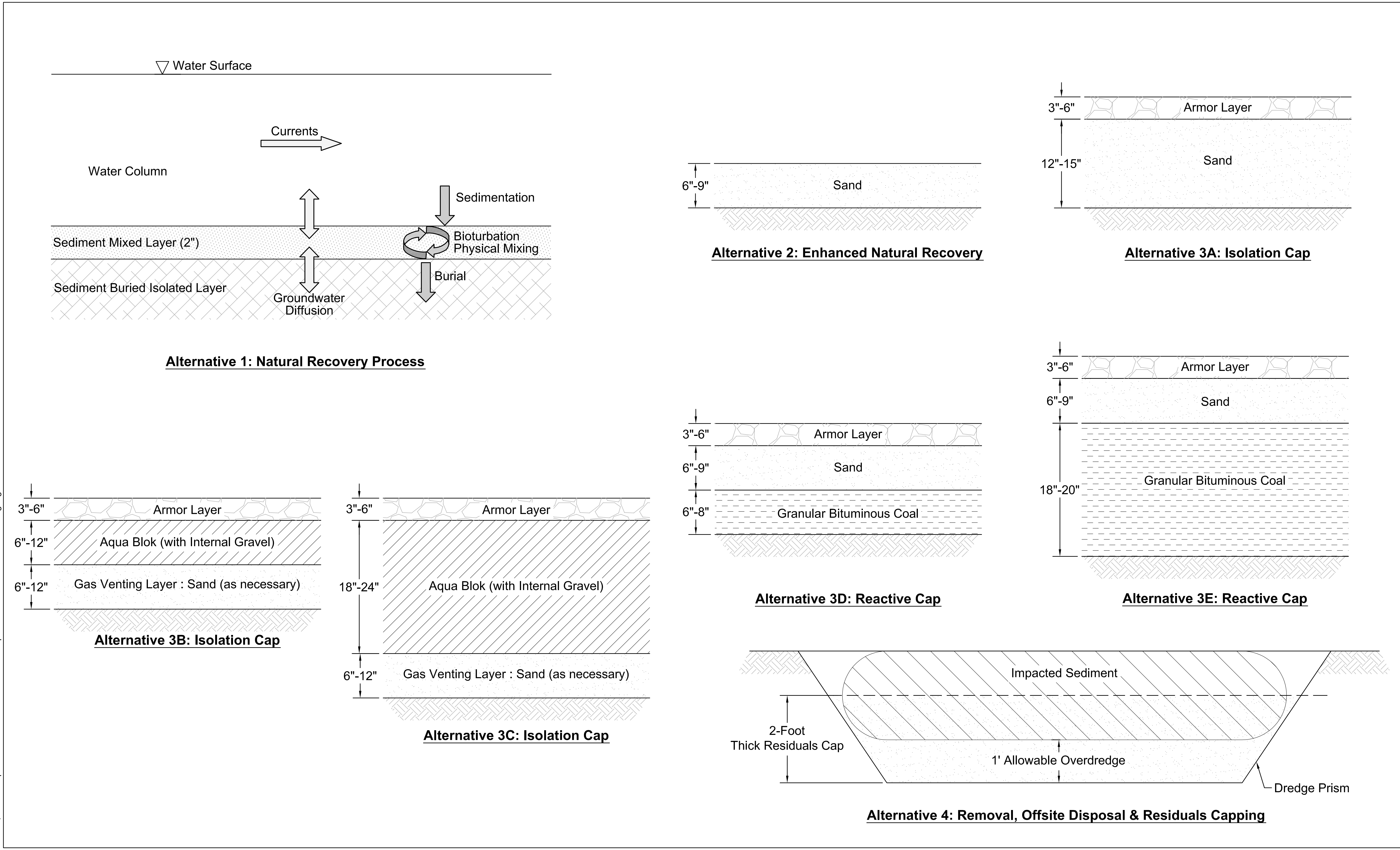
Four different remedial action options, spanning the range of potentially feasible response actions typically available for sediment sites, were developed for the Site, including:

1. Monitored natural recovery (MNR)
2. Enhanced natural recovery
3. Engineered sediment capping, considering a range of process options including different cap thickness and isolation layer material specifications as follows:
    a. Permeable sand layer
    b. Low permeability clay layer
    c. Permeable reactive sorptive layer
4. Removal and off-site disposal

At Ecology's direction, the No Action alternative was not carried forward in this Focused FS. The sections below discuss development of each remedial action alternative carried forward for detailed FS evaluations of Deposits 1 and 2 (Figure 1).

5.1 Alternative 1: Monitored Natural Recovery

As discussed in Davis et al. (2004), MNR is a risk management alternative that relies upon natural environmental processes to permanently reduce exposure and risks associated with contaminated sediments. Figure 4 presents a schematic of sediment management alternatives including the MNR process. This option relies on sediment deposition (burial) and contaminant attenuation processes which have been documented in Deposit 1 (see Figure 2). Under this option, along with all other remedial alternatives, it is assumed that upstream source controls for PCBs, as necessary, would be implemented by independent third parties under existing wastewater discharge permits and future total maximum daily loading (TMDL) allocation-based limits. The effectiveness of MNR would be verified through long-term monitoring.



ANCHOR ENVIRONMENTAL, L.L.C.

Figure 4
Remedial Alternatives
Upriver Dam
Spokane, Washington

A weight-of-evidence approach for developing and evaluating appropriate MNR remedies at contaminated sediment sites has recently been developed by the Remediation Technologies Development Forum (RTDF) Sediment workgroup (Davis et al. 2004), and has been adopted by EPA in its sediment management guidance. The approach includes steps such as data assessment, modeling, and site monitoring, employing methods and approaches that have been successfully applied at other similar sites. The framework includes five interrelated elements:

1. Characterize contamination sources and controls.
2. Characterize fate and transport processes (both sediment and contaminant).
3. Establish historical record for contaminants in sediments.
4. Corroborate MNR based on biological endpoint(s) trends, if possible.
5. Develop acceptable and defensible predictive tools.

Each of these elements is briefly described below.

Characterize external contamination sources and controls. A critical component in the evaluation of any sediment management option, including MNR, is to characterize historic and current contaminant loading to the sediment site from external sources. Part of this understanding involves quantifying ongoing contaminant loading (e.g., annual mass releases of PCBs) to the site, and how such loading compares with historical releases. Because of the complexities often associated with contaminant loading processes, source characterization can be difficult, and the level of effort required highly site-specific.

As discussed above and generally depicted on Figure 2, chemical and radioisotope profiling performed in Upriver Dam PCB Deposit 1 reveals that current PCB loadings are far lower than conditions that existed at the Site in the 1950s and 1960s. Present-day sediment PCB inputs to the Site are currently being characterized by Ecology as part of TMDL sampling activities, and include total PCB analyses of suspended particulate matter (SPM) collected in 2003 near Plante's Ferry (roughly RM 85); initial results indicate total PCB concentrations of approximately 9 μg/kg dw measured in SPM at this location (J. Roland, personal communication 2004). Similarly low sediment input concentrations (i.e., in surface sediment "fluff" materials) were also reported by Hart Crowser (1995). Thus, based on the available data, existing PCB inputs to the Upriver Dam Site appear to be below the conservative SQV of 60 μg/kg dw. Nevertheless, additional PCB source controls may be implemented under existing wastewater discharge permits and future TMDL allocation-based limits.

Characterize fate and transport processes (both sediment and contaminant). Assessment of contaminant fate and transport processes in support of MNR requires understanding of environmental processes affecting both sediment and contaminants (Magar et al. 2003). Primary processes of interest include settling/deposition, long-term burial, bioturbation and biological mixing in the bed, porewater diffusion and advection, and chemical partitioning. As discussed above, many of these parameters, including the net sedimentation rate (0.4 to 1.0 cm/yr) and depth of the bioturbation/mixing layer (the top 4 cm of the 10 cm biologically active zone) have been characterized through prior radioisotope core profile analysis (see Figure 2).

Information on sediment stability is often necessary to assess the long term integrity of the sediment bed and understand the effects of rare, extreme event conditions on contaminant and sediment mobility (Erickson et al. 2003). Evaluation of MNR requires assessing long-term stability, to ensure contaminant isolation under normal and relatively extreme hydrodynamic events that can cause elevated erosional conditions (e.g., 100-year return frequency events). Evaluation of future bed stability can be conducted in a number ways, including inference from empirical evaluation of historical data (see Figure 2 core profiles), and/or prediction based on deterministic models of extreme event stresses and potential sediment transport (see Appendix A). This approach coupled with a review of historical hydrodynamic records can indicate whether the observed historic record reflects impacts of past extreme events.

The maximum daily flow measured over that past 110+ years in the Spokane River (i.e., since 1891 at the downstream Spokane gage) is approximately 49,000 cfs (Figure 5). For comparison, daily flows above 40,000 cfs have occurred twice since the period of peak sediment PCB deposition within the Site (i.e., 1950 to 1960; Figure 2). In addition, breaching and washout/failure of the Upriver Dam powerhouse (and concurrent lowering of the pool) occurred in response to a lightning strike and resultant overflows in 1986 (http://emd.wa.gov/3-map/a-p/hiva/36-hiva-table-9.htm). Thus, sediments in identified PCB deposits at the Site have already been subjected to certain extreme hydrodynamic events.

For Deposit 1, dam failure along the north boundary of the channel is an example of a worst case scenario where scour and remobilization might occur. More likely but less dramatic erosion forces include flood event velocities and disturbances caused by foreign objects such as sunken trees and limbs. In general, the stability of these sediments as reflected in the core profile data (Figure 2) indicates that the bed in these areas has remained generally stable over time under the range of dynamic processes in the river system including the overflow in 1986.

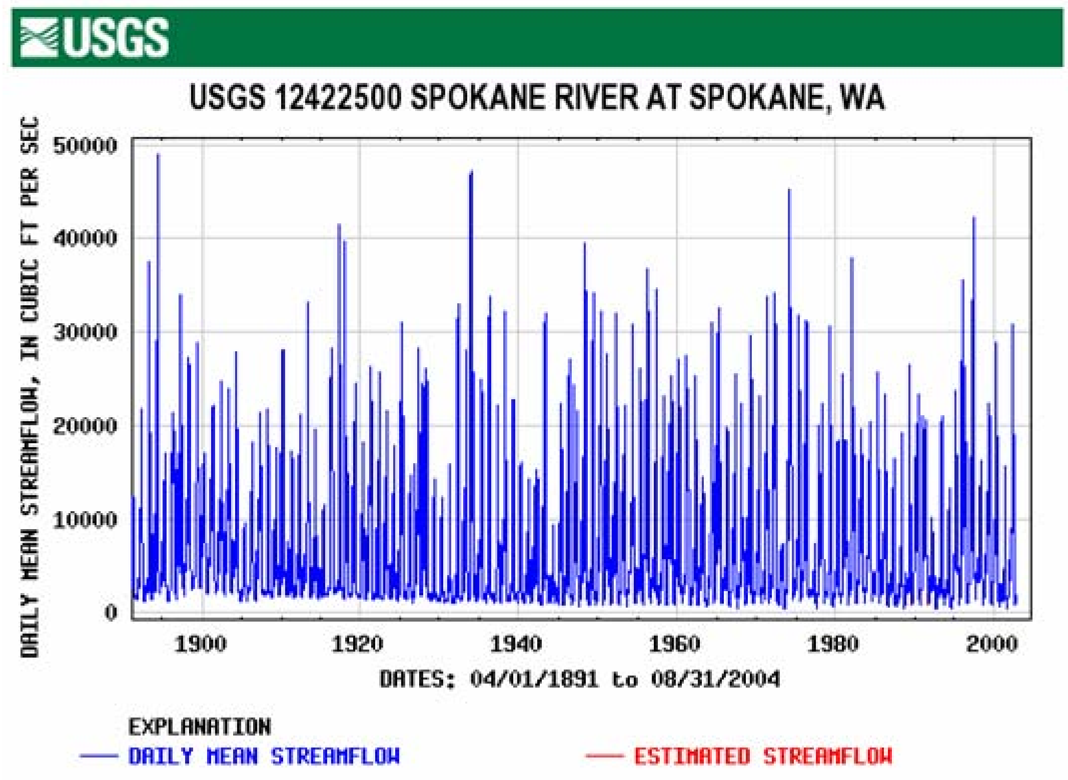


Figure 5
Historical Flows in the Spokane River, 1891 to 2003

In addition, porewater diffusion and/or advective processes represent another mechanism of potential PCB transport into the water column or into groundwater, as discussed in the RI (see Section 1.1 above).

Establish historical record for contaminants in sediments. Chemical concentration data assembled from past sampling events or from radioisotope-dated cores can be used to establish a historical record for contaminated sediments, and confirm the rate and extent of prior natural recovery (Magar et al. 2002; Patmont et al. 2003). As discussed above, the available coring record within Deposit 1 at the Upriver Dam Site provides evidence of recovery following peak loadings of PCBs to the river system that occurred in the 1950s and 1960s (Figure 2).

Corroborate MNR based on biological endpoint(s) trends, if possible. The objective of this MNR element is to confirm that risk reduction, as may be indicated by evaluation of chemical conditions, is corroborated using relevant biological measurements (Patmont et al. 2003). In many sediment site risk assessments, biological endpoints serve as the primary line of evidence for assessing human health and/or ecological protection. As a result of a range of EPA and Ecology sponsored studies, the ecological and human health risks associated with metals and other co-occurring contaminants in Spokane River sediments, including within the Upriver Dam area, have been well documented. For example, sediment toxicity measured throughout large areas of the Coeur d'Alene basin, extending into the Upriver Dam area, is consistent with risk-based models of metals toxicity (EPA 2001, Johnson and Norton 2001). Potential ecological risks associated with PCBs at the Site, including those associated with fish bioaccumulation pathways, are discussed in Johnson (2001). Potential human health risks associated with fish consumption is discussed in health consults prepared by the Washington Department of Health.

Depending on the specific site conditions, particularly relevant natural recovery biological monitoring data often include fish tissue sampling of key biological endpoints such as tissue PCB residues. While currently there are not sufficient, comparable biological endpoint data available to support a robust statistical evaluation of declining temporal trends in fish tissue PCB concentrations at the Site, further data are being collected as part of Ecology's TMDL program to evaluate this condition. This Focused FS is directed towards control of sediment and surface water PCB exposures, using bioaccumulation model relationships previously incorporated by Ecology and EPA into promulgated water quality standards.

Develop acceptable and defensible predictive tools. The final element in developing MNR alternatives is evaluation of whether observed reductions in sediment risks can reasonably be expected to continue into the future at desired rates. Future forecasts of MNR effectiveness are most often accomplished though the use/development of predictive tools such as computer models (Dekker et al. 2003). In systems in which fate and transport processes driving recovery may be complex and may change with time, simple extrapolation of historical trends may not be appropriate. In such cases, models such as the SEDCAM model discussed in Ecology's Sediment User Manual can be useful tools to predict future behavior of the system. Key SEDCAM input parameters required for the Upriver Dam site model includes the following estimations:

- Net sedimentation rate = 0.4 to 1.0 cm/yr (this range of values was used in the SEDCAM model)
- Depth of the bioturbation/mixing layer = 4 cm (based on radioisotope and chemical concentration profile data, and consistent with literature reports at other similar freshwater sediment sites; Boudreau 1997)
- Depth of the biologically active zone = 10 cm (default value from Ecology's Sediment Cleanup User Manual)
- Sediment input PCB concentration = 9 µg/kg dw (from SPM measurements; J. Roland, personal communication 2004)

Results of the SEDCAM model applied to the maximum surface sediment (0 to 10 cm) PCB concentration detected at the Site (1,430 µg/kg dw measured in Deposit 1 during Ecology's October 2000 sampling) are summarized in Figure 6. The modeling output suggests that natural recovery (at this maximum PCB concentration location) will likely achieve the 60 µg/kg dw low-range SQV between approximately 2020 and 2050, depending upon the sedimentation rate. Recovery to the 350 µg/kg dw high-range SQV would occur sooner, likely between 2010 and 2020. If Alternative 1 were to be implemented at the Site, it is assumed that monitoring at approximately 5-year intervals would be performed to verify actual rates of recovery.

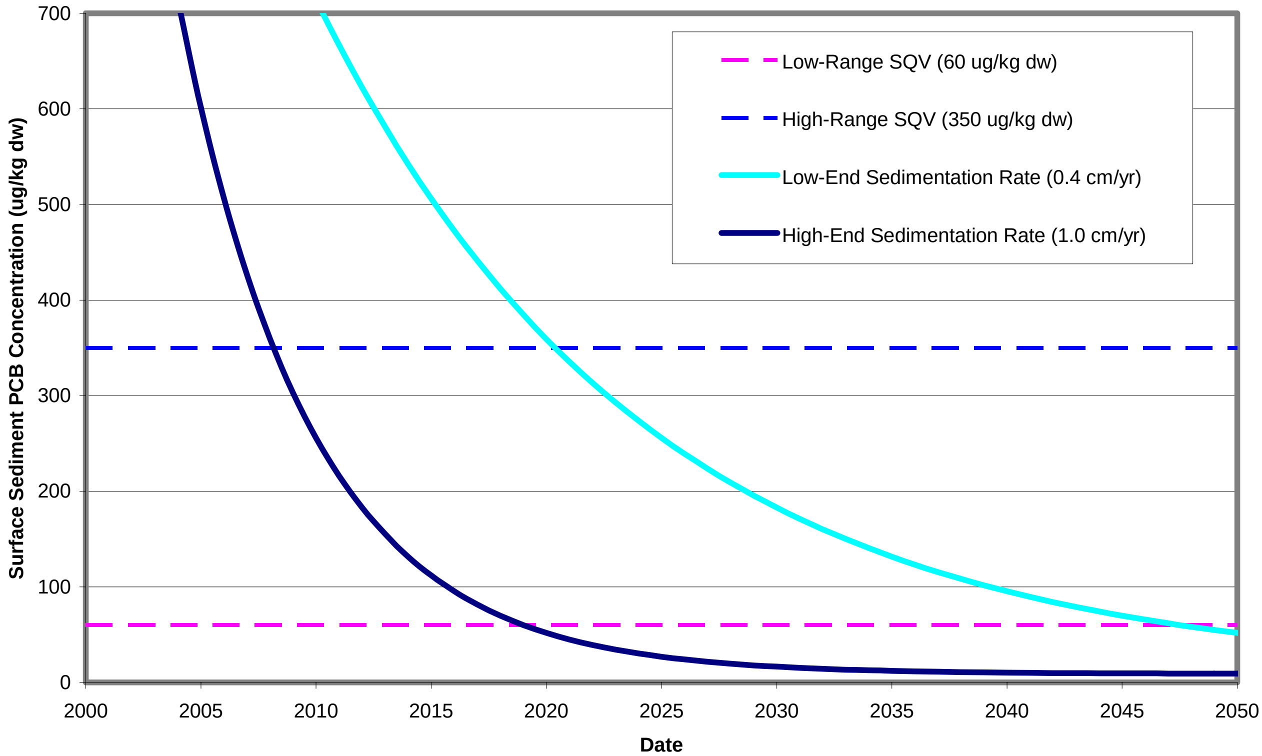


Figure 6
Predicted Natural Recovery of Maximum Surface Sediment PCB Concentrations in Upriver Dam Deposit 1; SEDCAM Model Predictions

5.2 Alternative 2: Enhanced Natural Recovery (Thin-Layer Capping)

This option would enhance the rate of natural recovery by placing a nominal 6-inch (15-cm) layer of clean sand over sediments that exceed the preliminary SQV (60 μg/kg dw). Figure 4 shows a typical cross-section of the alternative. Placement of the thin layer on top of existing sediments would facilitate more rapid attainment of the SQV within the top 10 cm biologically active zone. Compared with thicker sediment caps (see Alternative 3 below), application of thin-layer placement technologies is typically associated with significantly less short-term environmental impact, as existing sediment-dwelling benthos populations are able to migrate through the nominal 6-inch layer with relatively little mortality. The grain size composition of the cap would likely be a fine to medium sand. As discussed under Alternative 1, upstream source controls for PCBs, as necessary, would be implemented under existing wastewater discharge permits and future TMDL allocation-based limits. The effectiveness of enhanced natural recovery would be verified through long-term monitoring, though it is assumed that fewer monitoring events would be required to verify attainment and maintenance of the SQV, compared with Alternative 1.

The thin layer cap could be placed by a contractor using a number of different methods. At Deposit 1, the contractor would utilize either a mechanical or hydraulic system from the water. At Deposit 2, the contractor would likely place a thin cap from shore.

Placement of a thin-layer cap over Deposit 1 would require approximately 6,600 tons of sand, and could be completed over a period of approximately 1 to 2 weeks. Based on equipment tolerances and experiences at other similar sites, a contractor may need to place up to 12 inches of fine to medium sand to ensure that they obtain a 6-inch minimum thickness specification across the bottom. The sand would likely be brought to the site by truck and stockpiled on shore. If the contractor were to place the material mechanically, they would transfer the material to a barge. A crane on a barge would then use a clamshell bucket or equivalent equipment to place the material. The contractor would likely use differential global positioning system (DGPS) equipment to ensure location control during placement, and would monitor placement with soundings and/or cores.

Alternatively, the contractor could place the material hydraulically. In this case, the contractor would load the material from the stockpiles into a hopper and slurry the sand. The sand slurry would be pumped out to a diffuser barge located over the capping area. The diffuser barge would reduce the energy in the slurry, allowing the sand to fall through the water column and deposit on the sediment. The barge would be moved back and forth over the capping area using DGPS for location control. As with the mechanical approach, the contractor would use soundings and/or cores to monitor progress.

Placement of a thin-layer cap over Deposit 2 would likely be performed from shore. Based on an estimated 0.2 acres of sediment with PCB concentrations exceeding 60 μg/kg dw, construction of the thin-layer cap would require approximately 300 tons of sand, and would require roughly 1 week to complete. The sand would be hauled to the site by truck and stockpiled nearby. The contractor would either place the material by bucket and crane or pneumatically from shore. Surveys and/or cores would be used to monitor thickness during placement.

Design and construction of the enhanced natural recovery option described above could be completed within 1 to 2 years of execution of a Consent Decree.

5.3 Alternative 3: Sediment Capping (5 Process Options)

This option includes placement of a clean sediment cap over areas of the Site that exceed the SQV (60 μg/kg dw), to isolate underlying materials from the biologically active zone and water column. Consistent with EPA and Corps regulatory guidance for conducting in situ capping at contaminated sediment sites (Palermo et al. 1998a and 1998b), the cap would be designed to provide three different functions:

1. Physical isolation of PCB-contaminated sediments below the biologically active zone (10 cm thick benthic environment)
2. Further stabilization of subsurface PCB-contaminated sediments from potential worst-case hydrodynamic forces (i.e., erosion protection)
3. Reduction of transport (flux) of dissolved PCBs into the overlying water column

EPA and Corps cap design guidance also includes long-term monitoring, maintenance, and adaptive management elements to ensure the long-term integrity and performance of the cap system. Remedial design of the cap system is normally based on engineering analyses applied to reasonable worst-case conditions (e.g., a 100-year flood event), to ensure the long-term integrity and performance of the remedial action. Typically, performance and confirmation monitoring of contaminated sediment cap systems constructed in Washington State and elsewhere in the U.S. has occurred during Years 2, 4, and 9 following completion of the remedial action, with subsequent monitoring triggered by the occurrence of a design level hydrodynamic event such as a 50-year flood.

5.3.1 Capping Materials

Fine-grained as well as granular (sandy) materials have been demonstrated to be effective sediment caps (Brannon et al. 1985). However, most remedial in situ capping projects conducted to date have used sand materials, largely because of availability, relatively low cost, ease of placement, and stability in sloped areas (Palermo et al. 1998a and 1998b). While finer-grained material can provide a better chemical flux barrier than sands because of higher sorption capacity and lower permeability, use of finer-grained materials in remedial cap design to date has been limited by logistical difficulties associated with effective placement of such material on inundated substrates. Finer grained caps can often hinder movement of porewater and groundwater contaminants, and thus can control flux into the overlying water column and/or underlying groundwater.

Coarser grained caps are often more suitable for sediments with significant upwelling groundwater discharge into surface water, as finer-grained caps placed in such environments may be prone to uplift. Based on available regional hydrogeologic data (Patmont et al. 1985; Anchor and Hart Crowser 2003), the delineated sediment deposits in Upriver Dam (Figure 1) are in groundwater recharge areas (river exfiltration into the aquifer). Thus, hydraulic uplift is likely not a significant limitation of fine-grained caps that may be considered at the Upriver Dam PCB Site. Conceptual designs of capping systems for Deposits 1 and 2 developed for this Focused FS also considered site preparation (e.g., wood debris removal), armoring, and potential gas production, as discussed below.

Several commercial products have recently been developed that allow for the placement of finer-grained cap materials in freshwater environments. The material that has been used most often in this capacity is AquaBlok™ (Hull et al. 1999, Hull and Stephens 2000), which is a patented technology including a blend of clay minerals, polymers, and other additives surrounding a dense aggregate nucleus such as gravel. For typical product formulations, the clay component is often comprised largely of bentonite, although other clay-sized materials can be used in product preparation to address specific requirements. When applied in sediment capping applications, AquaBlok™ particles settle through the water column to the mudline. Within several weeks, the applied layer of AquaBlok™ particles hydrates and expands, coalescing into a cohesive and low-permeability barrier cap between the contaminated sediments and the overlying water. The gravel component of the mixture (e.g., nominal 1-inch material) provides erosion protection, or can be supplemented if necessary with more conventional armor designs. AquaBlok™ has been used in several successful in situ capping demonstration projects (e.g., Grasse River, New York; McShea et al. 2002) and in full-scale applications (Eagle River Flats, Anchorage, Alaska; Kate and Racine 1996, Hull and Stephens 2000).

More recently, sediment cap design has become increasingly focused on the addition of a range of "active" materials to cost-effectively control contaminant mobility and/or encourage degradation by sequestering the chemical onto a suitable media (see McLeod et al. 2004). A major demonstration of several of the more promising active cap designs is now underway on the Anacostia River in Washington, DC (Reible and Constant 2004). The objective of the Anacostia River demonstration project, which began field trials in spring 2004, is to provide information on the design, construction, and placement of active caps. Initial bench-scale treatability testing assessed the feasibility and expected effectiveness of a range of active cap technologies, and identified the most promising technologies for field-scale demonstration. While various cap technologies were evaluated, the following were selected for use in the demonstration:

- Sand, used in the Anacostia River demonstration as a control
- AquaBlok™, a commercial product designed to enhance chemical sequestering (e.g., through TOC amendments to the cap) and reduce permeability at the sediment-water interface (see above)
- Apatite, which encourages precipitation and sorption of metals (though not directly applicable to the Upriver Dam PCB Site)
- Coal and/or coke breeze materials, which can strongly adsorb hydrophobic organic contaminants such as PCBs

A range of the most promising sand, AquaBlok™, coal, and armor material options that provide for containment and mobility control of PCBs at the Upriver Dam Site were considered as potential capping options in this Focused FS, as discussed in more detail below.

5.3.2 Cap Thickness and Placement Considerations

Conceptual designs and evaluations of in situ caps performed for this Focused FS followed the detailed cap design guidance developed by the EPA and Corps (Palermo et. al. 1998a and 1998b). The guidance recommends that caps be designed and constructed (i.e., sufficient thicknesses of suitable materials placed above contaminated sediments) to ensure protection from surface erosion/mixing forces and groundwater/porewater transport processes. The surface armor layer of a cap is designed to resist the following reasonable worst-case erosion/mixing forces:

- **Peak river currents** – 100-year peak flood conditions (addressed in this Focused FS with conservative modeling; see below and Appendix A).
- **Wind and vessel generated waves** – Since Deposit 1 sediments are located in water depths greater than 20 feet, and because wave effects even under peak conditions will be limited to the upper 4 to 5 feet of the water column, this potential erosion force is minimal, particularly in comparison with the 100-year flood condition.
- **Vessel propeller wash** – Vessel use in the prospective capping areas are predominantly recreational craft, with the relatively low potential to generate significant propwash currents, particularly in comparison with the 100-year flood condition.
- **Ice** – Because of the depth of Deposit 1, potential ice scour is not an issue within these areas, but may be a consideration in Deposit 2. However, ice in the Donkey Island side channel area typically would not freeze down to the cap surface, and thus has a low potential for ice gouging and associated erosion.
- **Anchor drag and other potential human contact** – Again, because of the depth of the prospective caps and use of the area by recreational craft, anchor drag and contact by humans from wading or walking is not expected to be an issue. Anchors dropped onto or dragged across a granular cap may induce temporary, isolated injuries to the cap. However, the granular material side walls created by the anchor impact are expected to slough back into the impact area and are thus self healing. Consequently, potential anchor effects are not expected to materially impact cap integrity.
- **Bioturbation** – As discussed above, the depth of the bioturbation/mixing layer measured in Deposit 1 is 4 cm (approximately 2 inches), however for the purpose of cap design the surface bioturbation layer was conservatively set at 10 cm (4 inches), corresponding to the maximum depth of the biologically active zone (from Ecology's Sediment Cleanup User Manual).

An additional capping consideration in the Upriver Dam area is the potential for disturbance of the sediment cap caused by foreign objects such as sinking trees or limbs that may settle onto the capped areas. For the purpose of this Focused FS, shallow foundation bearing capacity models were used to evaluate the effect of a worst-case 3-

foot-diameter log that could potentially settle onto the cap. For this analysis, the log was evaluated as a long strip footing (Das 1984). Strength parameters for regional sand and AquaBlok™ cap materials were based on available laboratory test data, along with past experience with similar materials. Loads from the log bearing on the different caps were calculated assuming a range of different unit weights of sunken logs, as specific data were not available on the density of sunken logs in the Spokane River.

For the range of potential sand, AquaBlok™, and cap armor materials considered in this Focused FS, the foundation analysis revealed that log densities greater than 100 pounds per cubic foot (pcf), or more than 50 percent greater than that of water, would be required to exceed the bearing strength of the cap. Since log densities of this magnitude are not expected (typical sunken log densities range up to 70 to 80 pcf), prospective cap designs developed for this Focused FS provide an additional safety factor against potential bearing failure. Therefore, a log settling or resting on any of the caps evaluated in this Focused FS is not expected to materially injure the cap(s) under static conditions.

The potential for a log to injure the cap under a dynamic condition, such as a storm event, was evaluated qualitatively, as there is a low likelihood that a log would impact the cap during a high flow event. That is, all of the sediment areas being considered for capping are in backwater regions protected from primary river currents by upstream river meanders and/or banks (e.g., inside bends; Figure 1). Larger debris moving through the river would be directed towards the outside of the river bends, and away from Deposits 1 and 2.

As discussed above, long-term monitoring and adaptive management of the cap surface is included as an element of all of the capping alternatives developed and evaluated in this Focused FS to ensure the long-term integrity and performance of the cap system. In the event that monitoring data reveal that logs settle onto the cap, and in the unlikely scenario that material damage to the cap were to be observed, repair of the cap surface would be performed as part of long-term contingency and adaptive management actions.

Below the surface erosion/armor layer, the isolation layer is designed to ensure that groundwater/porewater/sediment transport from contaminated subsurface layers will not recontaminate the biologically active zone of the cap in the future. One dimensional groundwater transport analytical modeling, discussed in more detail in Section 6.2.3, was performed to determine the thickness of the required isolation layer under different capping options. The thickness of the isolation zone is also determined by the precision of placement methods, as cap placement in some settings can potentially result in mixing of cap materials with the underlying contaminated sediments.

All of the conceptual cap designs developed and evaluated in this Focused FS, including those with thinner layers of erosion and/or isolation materials, were developed in conformance with EPA and Corps cap design guidance (Palermo et. al. 1998a and 1998b). While the detailed cap specifications would need to be verified during final remedial design based on more detailed engineering analyses, all of the conceptual cap designs carried forward in this Focused FS are consistent with current regulatory design guidance, and thus should provide for long-term effectiveness and protection. At the request of Ecology, options employing greater cap thicknesses were also developed to evaluate whether additional protection or biological benefits beyond cleanup may be provided by further increasing cap thickness above the design guidance.

As discussed above, one of the key considerations in cap design is material placement capabilities. To test the ability to place active cap layers in thin lifts using available technologies, the layers were deposited at the Anacostia River demonstration site with a conventional clamshell bucket in 6-inch lifts. Since the specific gravity of coke is typically less than that of water, and because of the high reactivity of these materials (i.e., requiring much less than 6 inches of material to provide the desired adsorption characteristics), coke breeze was placed in a 1-inch mat enclosed in a geotextile. (Alternatively, similarly active materials such as peat or crushed bituminous coal, which have specific gravities greater than water, could have been placed directly on the site using a clamshell bucket, as has been suggested and demonstrated at various Puget Sound capping projects, and further evaluated in this Focused FS.)

The active sediment cap designs for the Anacostia River demonstration included two layers: a reactive layer of variable thickness, and an overlying protective sand layer of 6 inches (15 cm). Both the reactive layer and the overlying sand layer isolate the contaminated sediments physically and chemically. The upper sand layer is typically designed to contain the lower active layer (and associated contaminants) and provide a substrate suitable for benthic organisms. AquaBlok™ provides a finer-grained sediment surface that can also provide a suitable habitat for benthic macroinvertebrates, particularly compared with sand (Hull et al. 1999), and thus does not often require a sand cap.

In the Anacostia River demonstration pilot, only the AquaBlok™ layer was placed slightly thicker than the targeted design, a result caused by the difficulty in placing thin layers of this material, and by swelling due to hydration. Researchers from Louisiana State University, University of Texas and elsewhere are currently confirming initial results and will be evaluating the performance of the caps over the next several years.

All of the cap designs carried forward in this Focused FS include an initial debris sweep of the capping area to ensure that relatively uniform layers of cap materials are placed. As a general design "rule of thumb," in order to ensure that cap layers cover the site entirely, surface debris equal to or larger than the target cap thickness should be removed. Thus, for a nominal 6-inch cap, surface debris currently protruding more than 6 inches above the mudline should be removed prior to cap placement. Both sand and AquaBlok™ caps typically conform to and cover smaller debris. Costs for initial debris removal have been incorporated into all cap designs. In addition, the AquaBlok™ cap includes placement of a lower sand gas venting layer to ensure that gas buildup does not adversely affect long-term cap performance (Mutch et al. 2004; see Figure 4). The need for such a layer would be verified during final design.

Based on the results of pilot and full-scale capping projects performed to date, and in order to inform evaluations of potential remedies applicable to the Upriver Dam PCB Site, this Focused FS evaluated a number of different potential sediment capping process options, as follows: